Program Testing

(Lecture 14)

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Source

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Organization of this Lecture

- Introduction to Testing.
- White-box testing:
  - statement coverage
  - path coverage
  - branch testing
  - condition coverage
  - Cyclomatic complexity
- Summary

Black-box Testing

- Test cases are designed using only **functional specification** of the software:
  - Without any knowledge of the internal structure of the software.
- For this reason, black-box testing is also known as **functional testing.**

White-Box Testing

- Designing white-box test cases:
  - Requires knowledge about the internal structure of software.
  - White-box testing is also called <u>structural testing</u>.

Black-Box Testing

- Two main approaches to design black box test cases:
  - Equivalence class partitioning
  - Boundary value analysis

White-Box Testing

- There exist several popular white-box testing methodologies:
  - Statement coverage
  - Branch coverage
  - Path coverage
  - Condition coverage
  - Mutation testing
  - Data flow-based testing

Coverage-Based Testing Versus Fault-Based Testing

- Idea behind coverage-based testing:
  - Design test cases so that certain program elements are executed (or covered).
  - Example: statement coverage, path coverage, etc.
- Idea behind fault-based testing:
  - Design test cases that focus on discovering certain types of faults.
  - Example: Mutation testing.

Statement Coverage

- **Statement coverage methodology:**
  - **Design test cases so that every statement in the program is executed at least once.**

Statement Coverage

- The principal idea:
  - Unless a statement is executed,
  - We have no way of knowing if an error exists in that statement.

Statement Coverage Criterion

- Observing that a statement behaves properly for one input value:
  - No guarantee that it will behave correctly for all input values.

Example

```
int f1(int x, int y){
1 while (x != y){
2     if (x>y) then
3         x=x-y;
4     else y=y-x;
5 }
6 return x;          }
```

Euclid's GCD Algorithm

Euclid's GCD Computation Algorithm

- By choosing the test set {(x=3,y=3),(x=4,y=3), (x=3,y=4)}
  - All statements are executed at least once.

Branch Coverage

- Test cases are designed such that:
  - Different branch conditions
    - Given true and false values in turn.

Branch Coverage

- Branch testing guarantees statement coverage:
  - A stronger testing compared to the statement coverage-based testing.

Stronger Testing

- Test cases are a superset of a weaker testing:
  - A stronger testing covers at least all the elements of the elements covered by a weaker testing.

Example

- int f1(int x,int y){
- 1 while (x != y){
- 2 if (x>y) then
- 3 x=x-y;
- 4 else y=y-x;
- 5 }
- 6 return x; }

Example

- Test cases for branch coverage can be:
- {(x=3,y=3),(x=3,y=2), (x=4,y=3), (x=3,y=4)}

Condition Coverage

- Test cases are designed such that:
  - Each component of a composite conditional expression
    - Given both true and false values.

Example

- Consider the conditional expression
  - ((c1.and.c2).or.c3):
- Each of c1, c2, and c3 are exercised at least once,
  - i.e. given true and false values.

Branch Testing

- Branch testing is the simplest condition testing strategy:
  - Compound conditions appearing in different branch statements
    - Are given true and false values.

Branch testing

- Condition testing
  - Stronger testing than branch testing.
- Branch testing
  - Stronger than statement coverage testing.

Condition coverage

- Consider a boolean expression having n components:
  - For condition coverage we require 2^n test cases.
- Condition coverage-based testing technique:
  - Practical only if n (the number of component conditions) is small.

Path Coverage

- Design test cases such that:
  - All linearly independent paths in the program are executed at least once.
- Defined in terms of
  - Control flow graph (CFG) of a program.

Path Coverage-Based Testing

- To understand the path coverage-based testing:
  - we need to learn how to draw control flow graph of a program.
- A control flow graph (CFG) describes:
  - the sequence in which different instructions of a program get executed.
  - the way control flows through the program.

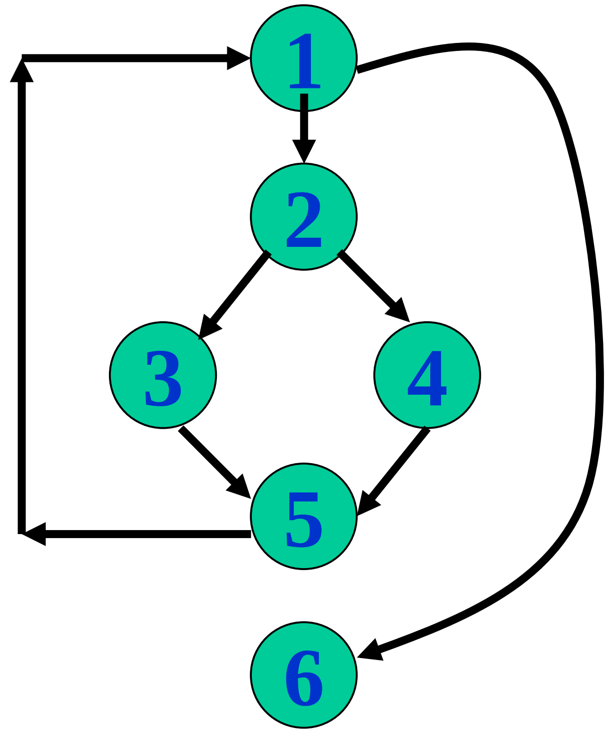
How to Draw Control Flow Graph?

- Number all the statements of a program.
- Numbered statements:
  - Represent nodes of the control flow graph.
- An edge from one node to another node exists:
  - If execution of the statement representing the first node
    - Can result in transfer of control to the other node.

Example

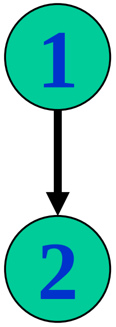
```
int f1(int x,int y){
1 while (x != y){
2     if (x>y) then
3          x=x-y;
4     else y=y-x;
5 }
6 return x;          }
```

Example Control Flow Graph



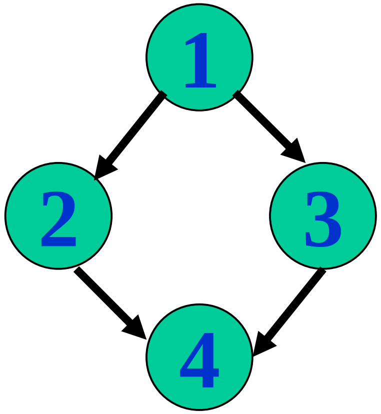
How to draw Control flow graph?

- Sequence:
  - 1 a=5;
  - 2 b=a*b-1;



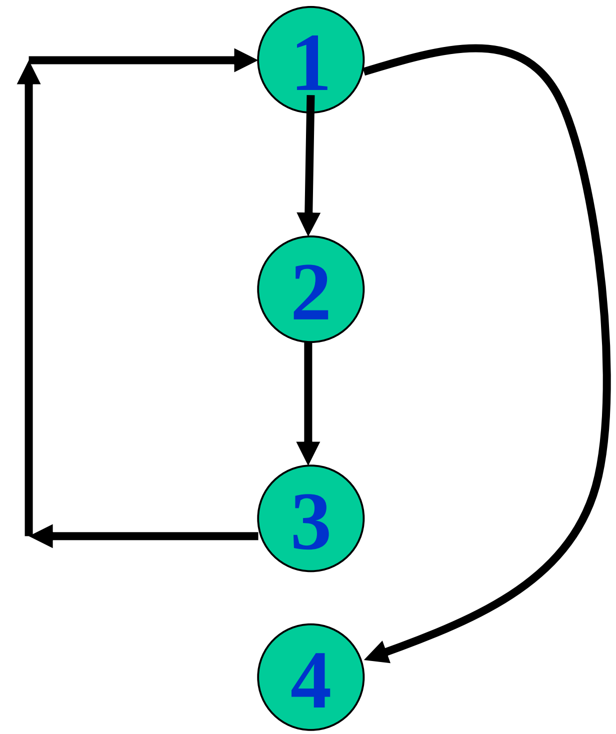
How to draw Control flow graph?

- Selection:
  - 1 if(a>b) then
  - 2 c=3;
  - 3 else c=5;
  - 4 c=c*c;



How to draw Control flow graph?

- Iteration:
  - 1 while(a>b){
  - 2 b=b*a;
  - 3 b=b-1;}
  - 4 c=b+d;



Path

- A path through a program:
  - A node and edge sequence from the starting node to a terminal node of the control flow graph.
  - There may be several terminal nodes for program.

Linearly Independent Path

- Any path through the program:
  - Introducing at least one new edge:
    - That is not included in any other independent paths.

Independent path

- It is straight forward:
  - To identify linearly independent paths of simple programs.
- For complicated programs:
  - It is not so easy to determine the number of independent paths.

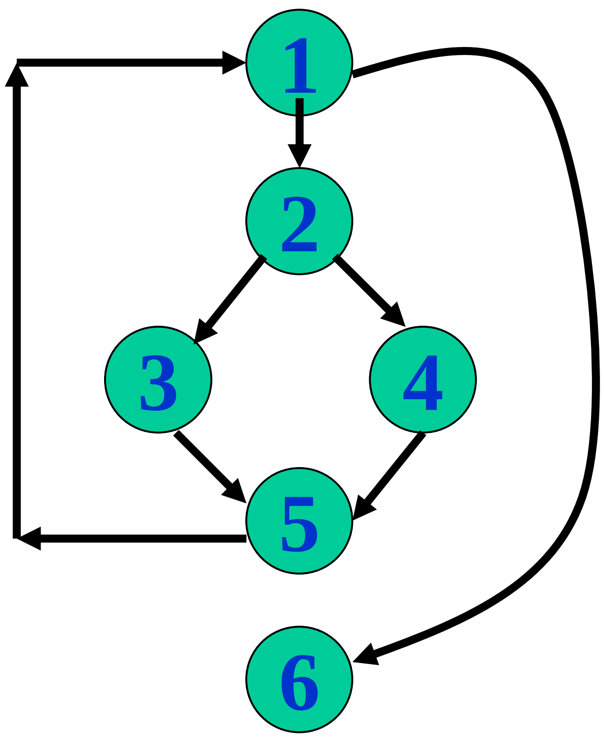
McCabe's Cyclomatic Metric

- An upper bound:
  - For the number of linearly independent paths of a program
- Provides a practical way of determining:
  - The maximum number of linearly independent paths in a program.

McCabe's Cyclomatic Metric

- Given a control flow graph G, cyclomatic complexity V(G):
  - V(G)= E-N+2
    - N is the number of nodes in G
    - E is the number of edges in G

Example Control Flow Graph

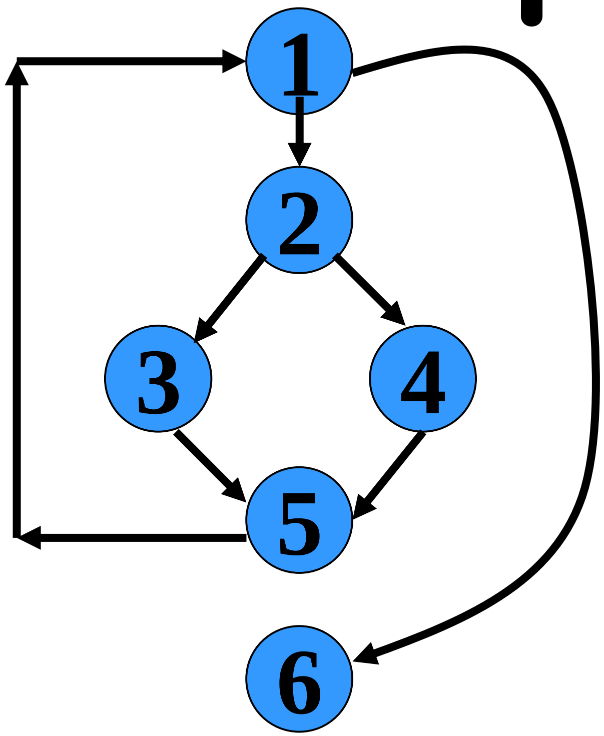


Cyclomatic complexity = 7-6+2 = 3.

Cyclomatic Complexity

- Another way of computing cyclomatic complexity:
  - inspect control flow graph
  - determine number of bounded areas in the graph
- V(G) = Total number of bounded areas + 1
  - Any region enclosed by a nodes and edge sequence.

Example Control Flow Graph



Example

- From a visual examination of the CFG:
  - the number of bounded areas is 2.
  - cyclomatic complexity = 2+1=3.

Cyclomatic complexity

- McCabe's metric provides:
  - A quantitative measure of testing difficulty and the ultimate reliability
- Intuitively,
  - Number of bounded areas increases with the number of decision nodes and loops.

Cyclomatic Complexity

- The first method of computing V(G) is amenable to automation:
  - You can write a program which determines the number of nodes and edges of a graph
  - Applies the formula to find V(G).

Cyclomatic complexity

- The cyclomatic complexity of a program provides:
  - A lower bound on the number of test cases to be designed
  - To guarantee coverage of all linearly independent paths.

Cyclomatic Complexity

- Defines the number of independent paths in a program.
- Provides a lower bound:
  - for the number of test cases for path coverage.

Cyclomatic Complexity

- Knowing the number of test cases required:
  - Does not make it any easier to derive the test cases,
  - Only gives an indication of the minimum number of test cases required.

Path Testing

- The tester proposes:
  - An initial set of test data using his experience and judgement.
- A dynamic program analyzer is used:
  - To indicate which parts of the program have been tested
  - The output of the dynamic analysis
    - used to guide the tester in selecting additional test cases.

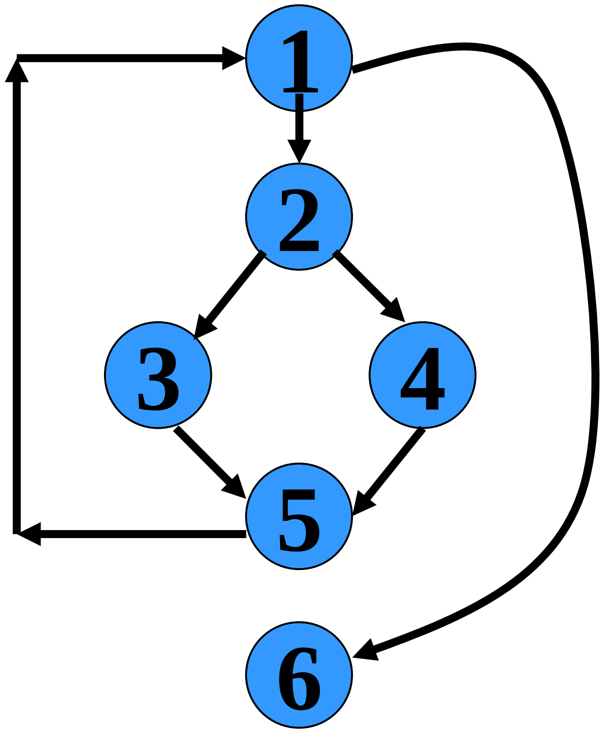
Derivation of Test Cases

- Let us discuss the steps:
  - to derive path coverage-based test cases of a program.
- Draw control flow graph.
- Determine V(G).
- Determine the set of linearly independent paths.
- Prepare test cases:
  - to force execution along each path.

Example

```
int f1(int x,int y){
1 while (x != y){
2      if (x>y) then
3           x=x-y;
4      else y=y-x;
5 }
6 return x;          }
```

Example Control Flow Diagram



Derivation of Test Cases

- Number of independent paths: 3
  - 1,6 test case (x=1, y=1)
  - 1,2,3,5,1,6 test case(x=1, y=2)
  - 1,2,4,5,1,6 test case(x=2, y=1)

An interesting application of cyclomatic complexity

- Relationship exists between:
  - McCabe's metric
  - The number of errors existing in the code,
  - The time required to find and correct the errors.

Cyclomatic Complexity

- Cyclomatic complexity of a program:
  - Also indicates the psychological complexity of a program.
  - Difficulty level of understanding the program.

Cyclomatic Complexity

- From maintenance perspective,
  - limit cyclomatic complexity
    - of modules to some reasonable value.
  - Good software development organizations:
    - restrict cyclomatic complexity of functions to a maximum of ten or so.

Summary

- Exhaustive testing of non-trivial systems is impractical:
  - We need to design an optimal set of test cases
    - Should expose as many errors as possible.
- If we select test cases randomly:
  - many of the selected test cases do not add to the significance of the test set.

Summary

- There are two approaches to testing:
  - black-box testing and
  - white-box testing.
- Designing test cases for black box testing:
  - does not require any knowledge of how the functions have been designed and implemented.
  - Test cases can be designed by examining only SRS document.

Summary

- White box testing:
  - requires knowledge about internals of the software.
  - Design and code is required.
- We have discussed a few white-box test strategies.
  - Statement coverage
  - branch coverage
  - condition coverage
  - path coverage

Summary

- A stronger testing strategy:
  - provides more number of significant test cases than a weaker one.
  - Condition coverage is strongest among strategies we discussed.
- We discussed McCabe's Cyclomatic complexity metric:
  - provides an upper bound for linearly independent paths
  - correlates with understanding, testing, and debugging difficulty of a program.